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THz Imaging Radar: Technology Development for Multi-pixel Multi-color Architectures

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Jet Propulsion Laboratory, California Institute of Technology

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WFC: Emerging Technology of THz Imaging Systems, Devices and Algorithms
Friday, June 22

Outline

- Motivation
- Imaging arrays
  - Methodology
  - Technology
  - Roadmap
- Conclusion

Introduction and Motivation

- Submillimeter-wave heterodyne receivers have a long and noteworthy history in exploring our universe (MLS, MIRO, HIFI)
- Recent work has also demonstrated the use of this technology for concealed weapons detection (Cooper et. al talk this conference)
- Most receivers deployed at these frequencies have been single pixel and fairly bulky systems
- Two important considerations require a paradigm shift in terms of how we build these receivers for the future
  - Large count arrays will require that each receiver is low-mass, low-power and extremely small.
  - A "batch level" technology is needed for manufacturing arrays.

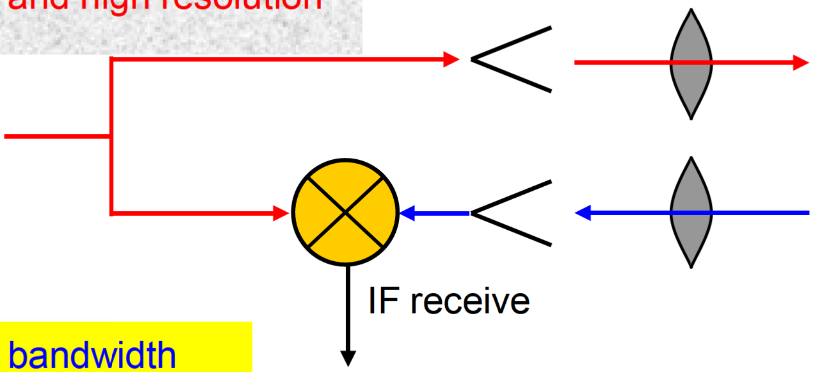
Submm Imaging Radar

Visible, IR | Microwaves, RF

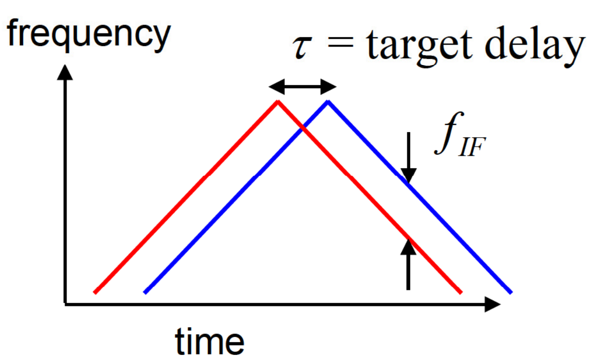
high resolution, but non-penetrating | THz Gap | penetrating, but low resolution

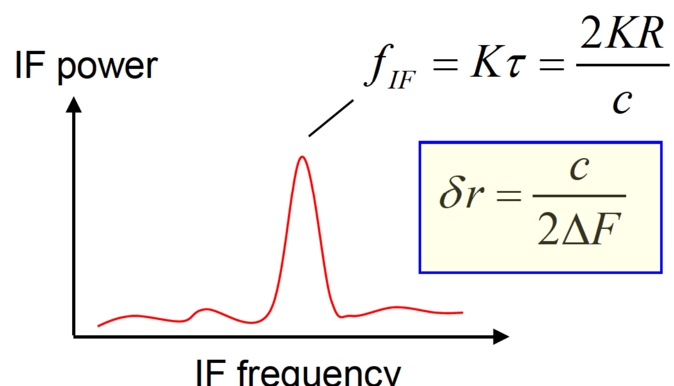
penetrating and high resolution

K = chirp rate (Hz/s)



Range resolution: inversely proportional to chirp bandwidth



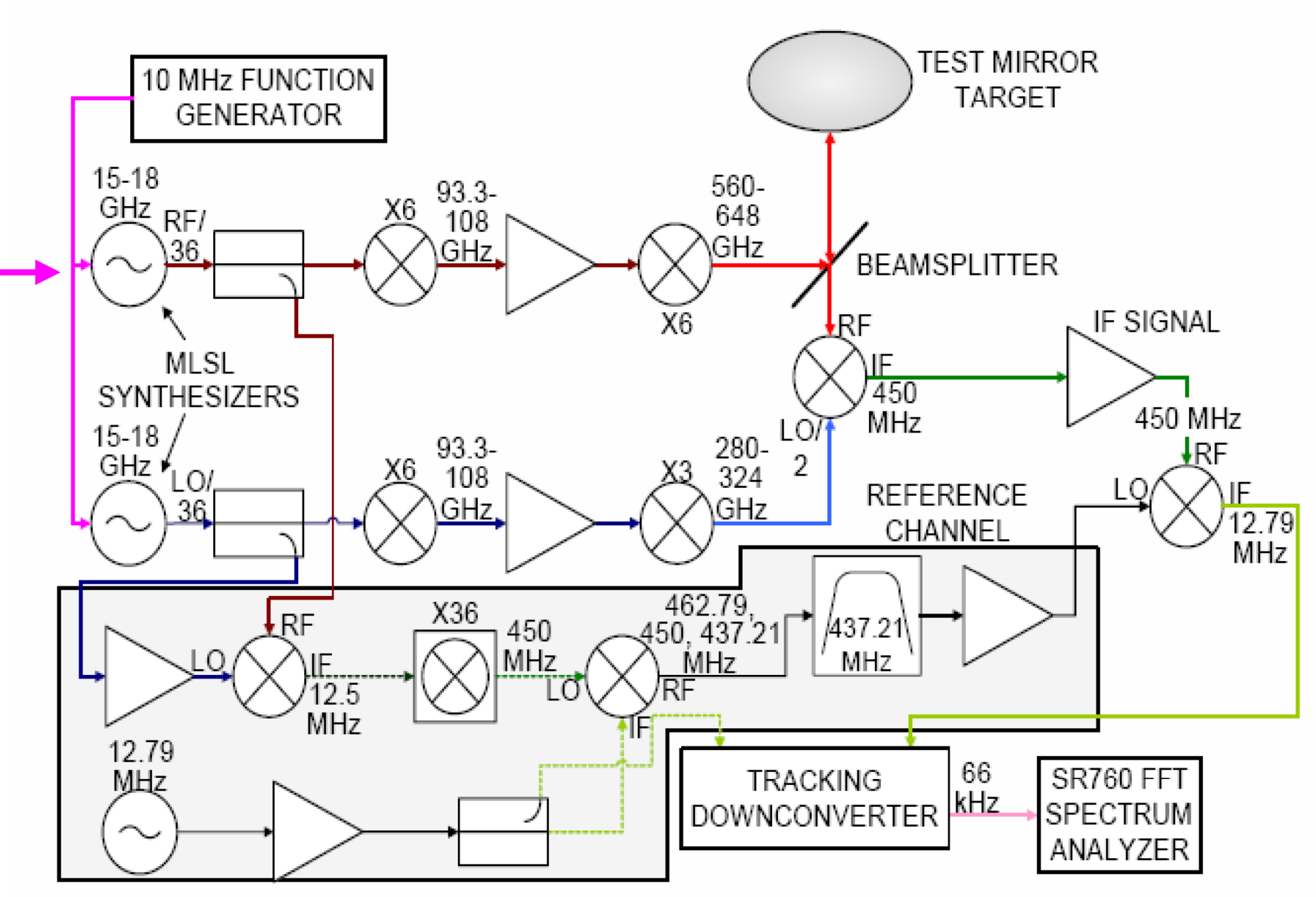


$$f_{IF} = K\tau = \frac{2KR}{c}$$

$$\boxed{\delta r = \frac{c}{2\Delta F}}$$

Evolution to FMCW Radar

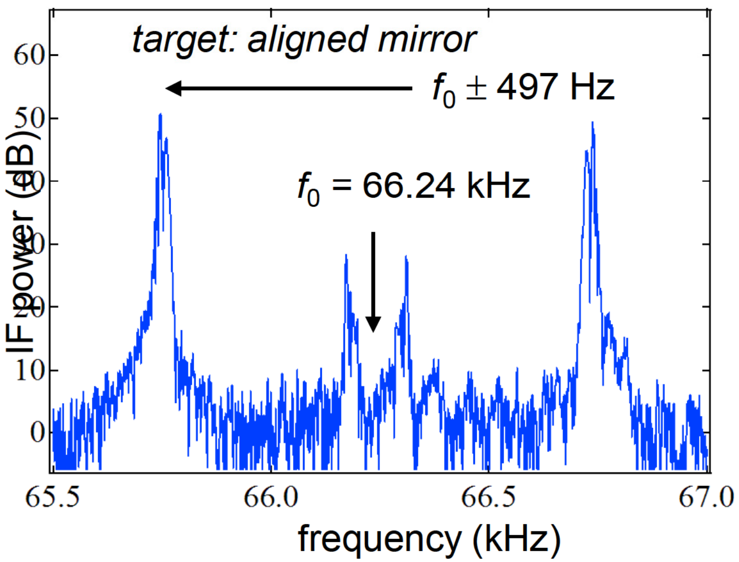
RF and LO simultaneously chirped by slowly (1 Hz) modulating 10MHz reference



First results, 2008

$$f_{IF} = f_0 + \frac{2KR}{c} = f_0 \pm 470 \text{ Hz}$$

630 GHz radar proof-of-principle achieved. First results:

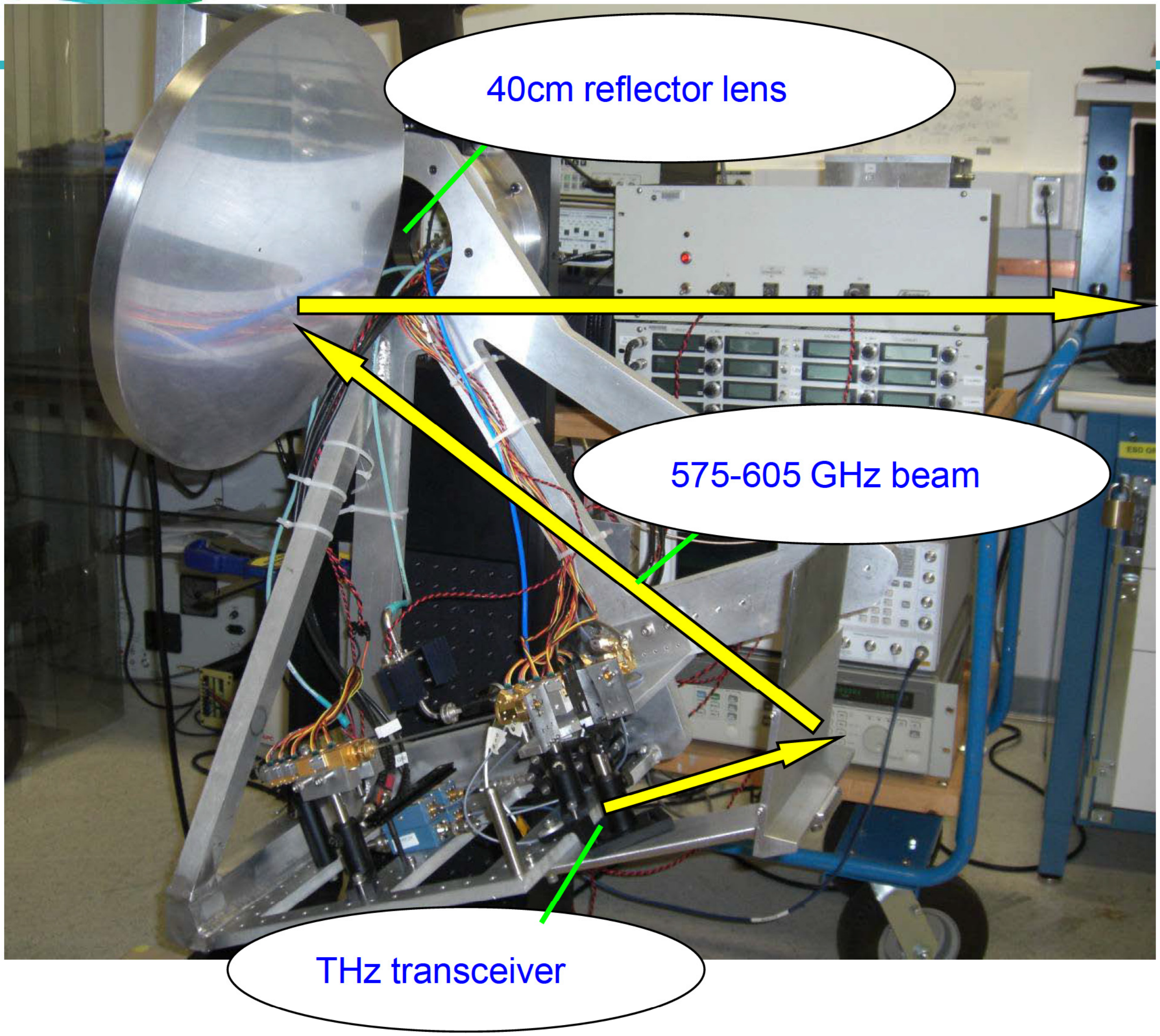


$$f_0 = 66.24 \text{ kHz} \qquad R = 4.4 \text{ m}$$

$$K = \pm \frac{8 \text{ GHz}}{0.5 \text{ s}} \qquad c = 3\text{e}8 \text{ m/s}$$

Problems: very noisy receiver and very slow chirp speed.

THz Imaging Radar Layout



Operating Parameters

Standoff range:
4-25 meters

Operating frequency:
575-605 GHz

Range resolution
~1 cm

Cross-range resolution:
~1 cm

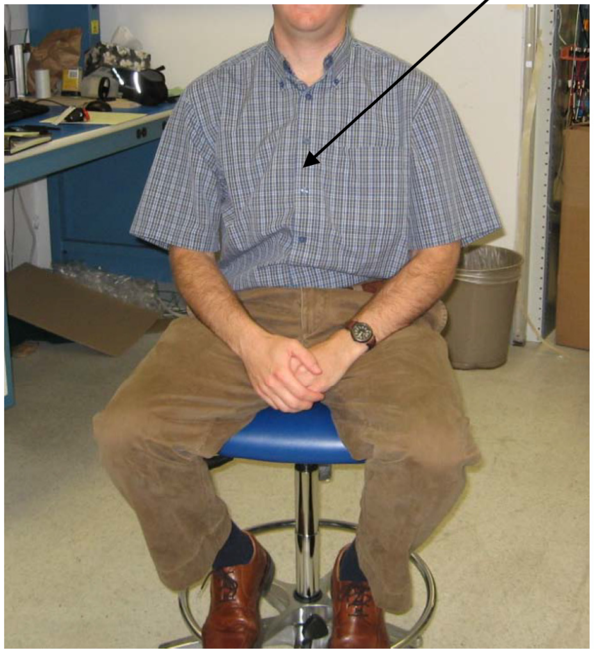
Output power:
≤0.4 mW

Time per pixel:
6-25 m s

Detection of Concealed Objects on People

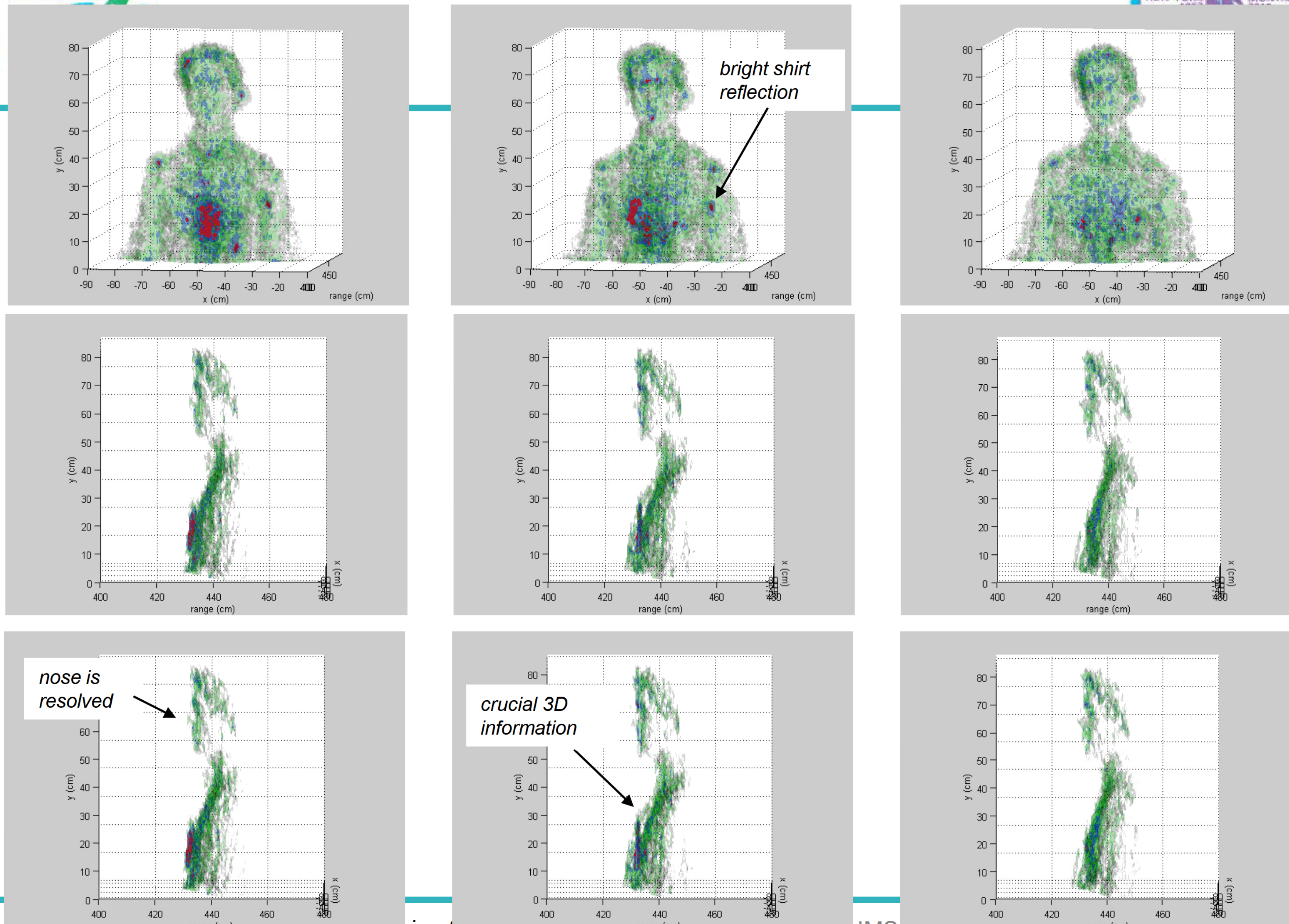
plastic container of BB pellets

BBs concealed by shirt



8 minute scans
100 x 110 pixels

BBs over shirt | BBs behind shirt | no BBs



Recent imaging at 25 m standoff distance

	Single pixel Radar
Frequency	670 Ghz
Spot size	~ 1 cm
FoV	25x25 cm^2
Range resolution	~ 1 cm
Standoff distance	Approaching 25 m
Frame rate	1 Hz

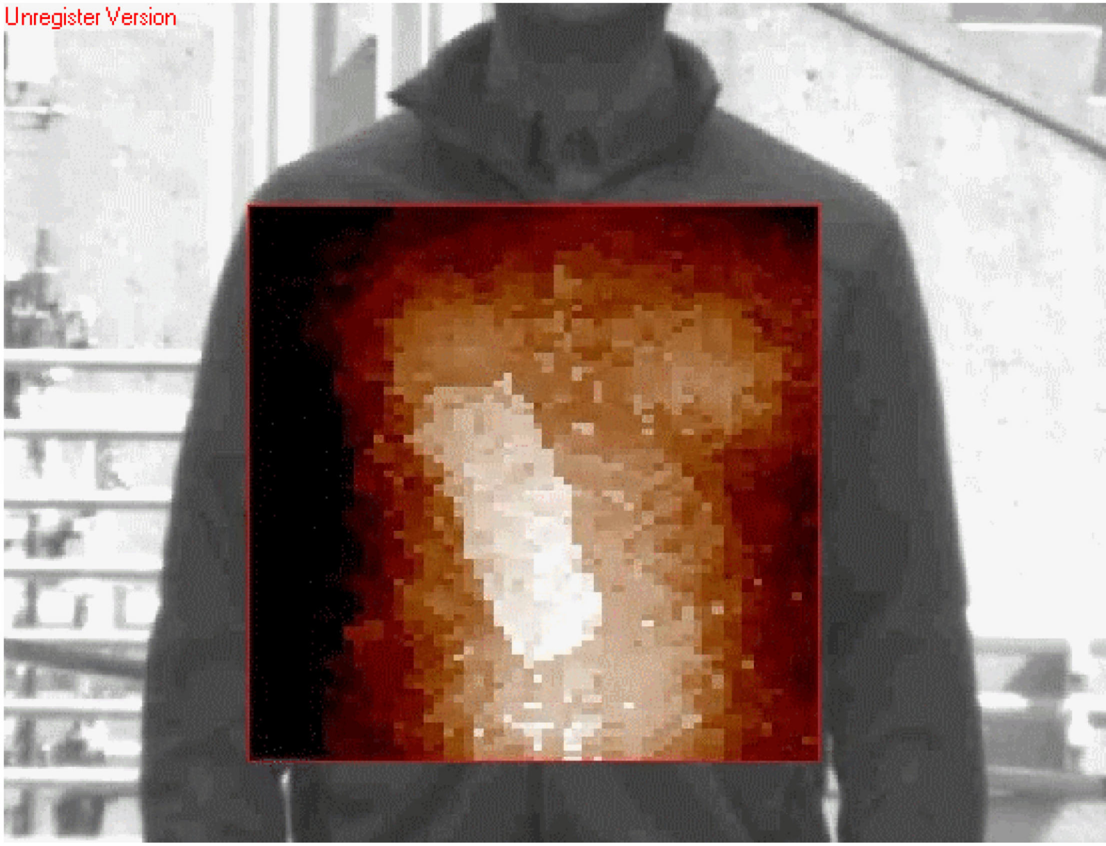
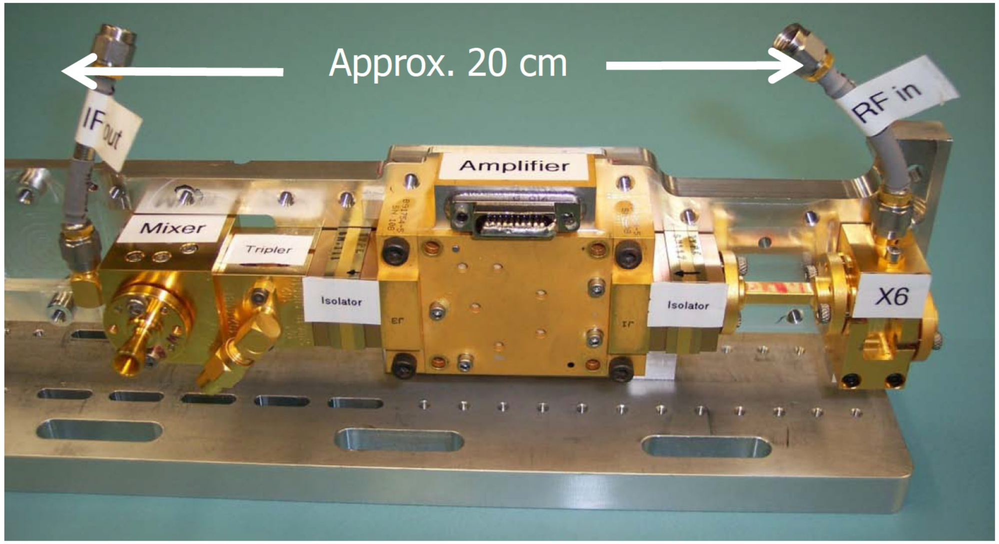


Image acquisition limited by switching mirror motor

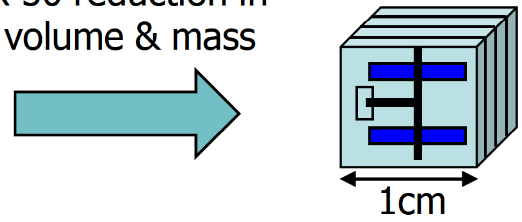
Technological Roadmap

Develop an ultra-compact receiver which is compatible with array architecture

SOA 500-600 GHz Receiver Front End

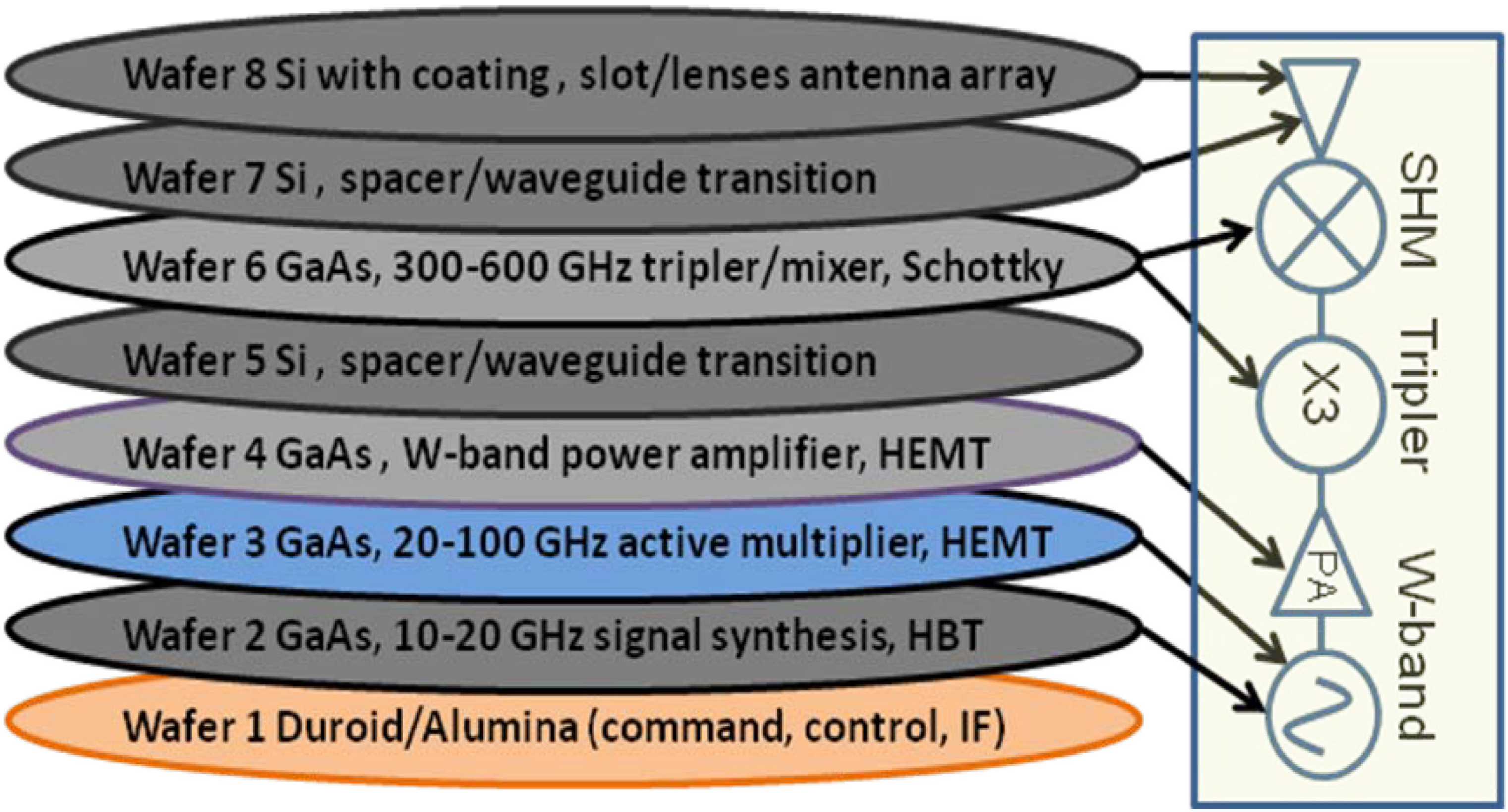


x 50 reduction in volume & mass



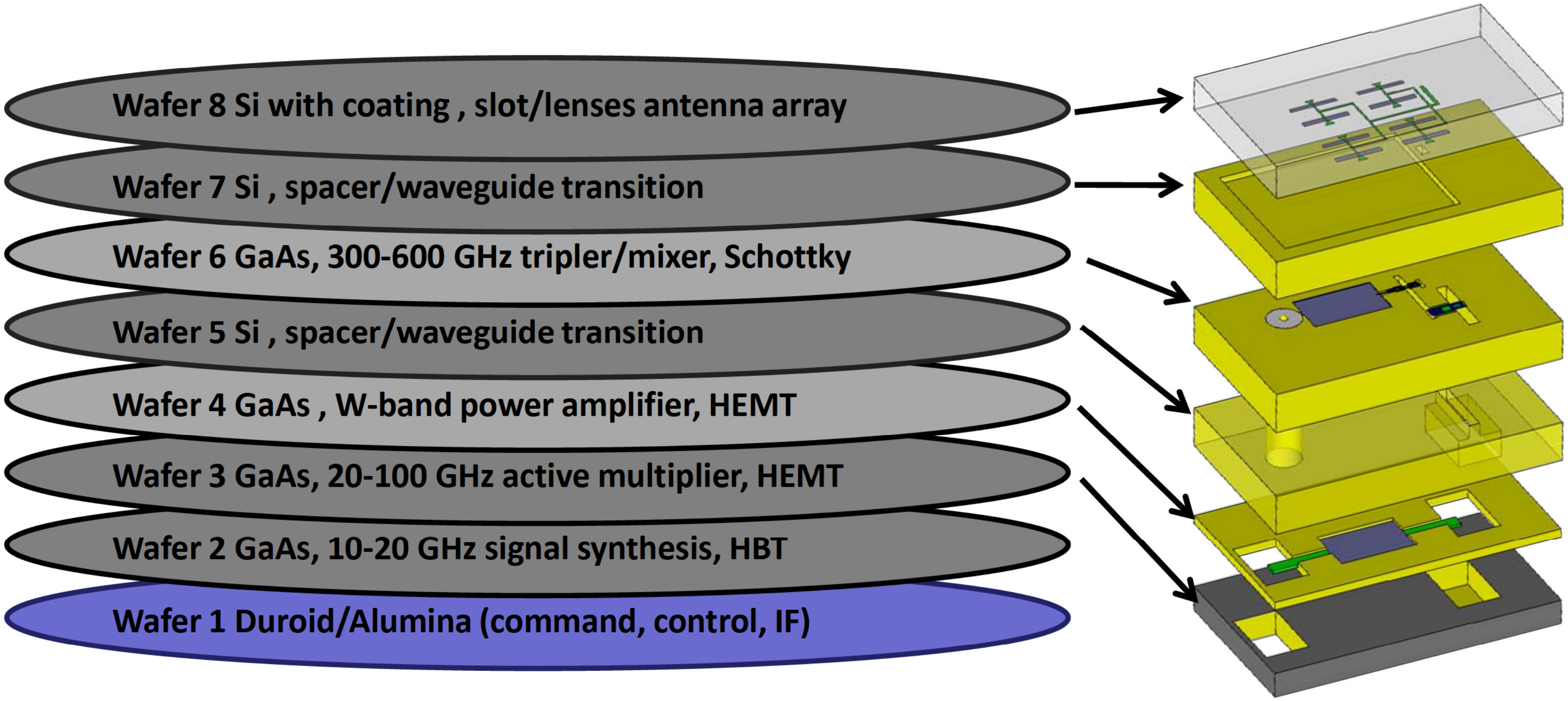
Radiometer-On-Chip (ROC) concept

- This novel architecture uses a stack of micro-machined wafers for waveguide components and interconnections, and MMIC based GaAs wafers for amplifiers, multipliers and mixers.



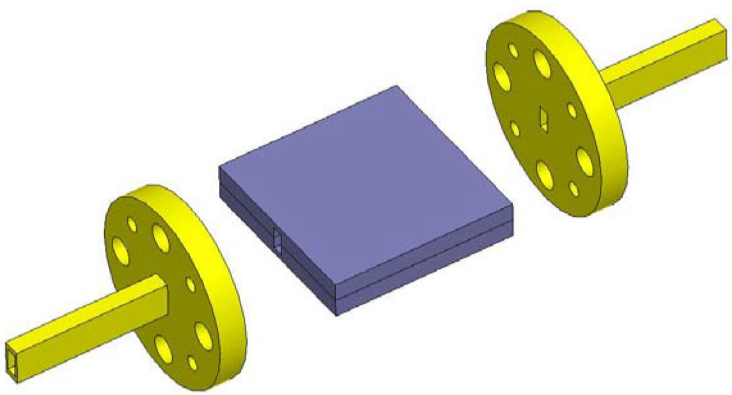
ROC modified for proof-of-concept

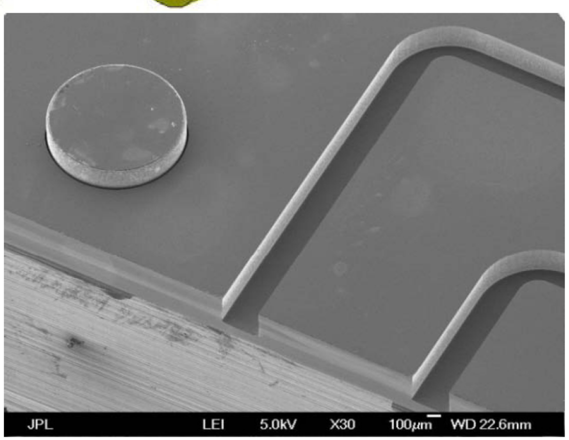
- Instead of more expensive GaAs wafers use Si wafers with discretely mounted GaAs based devices.



Si-metal waveguide interconnections

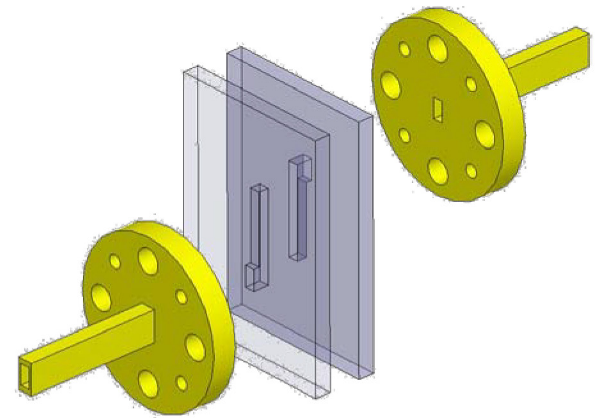
- 1st option: from the side of the Si wafer





Commonly used approach

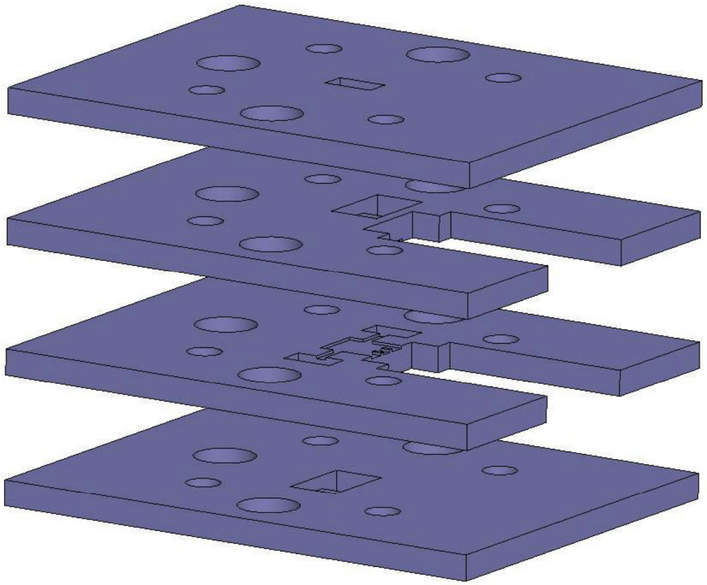
- 2nd option: from the flat of the Si wafer.

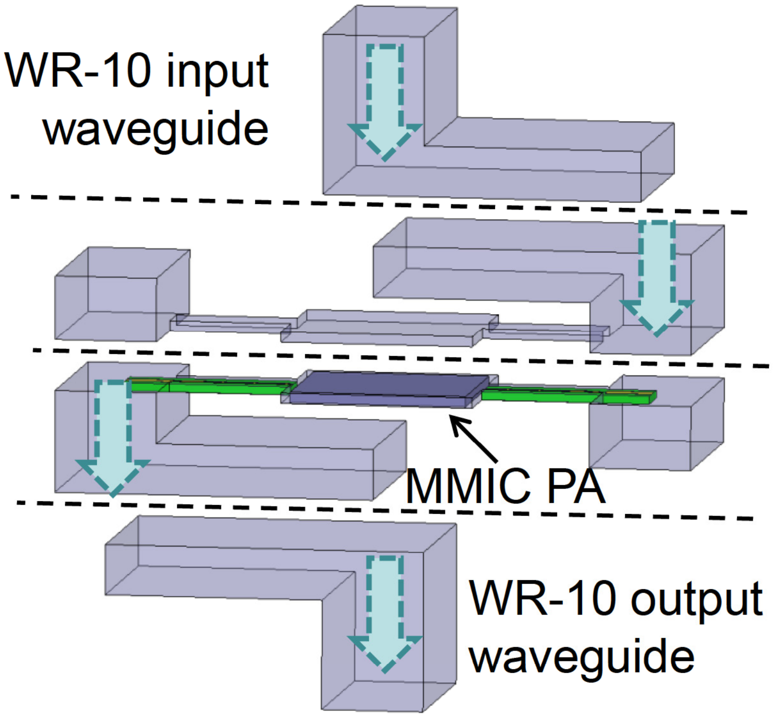


Our approach for interfacing

Super compact W-band Amp

- 4 Si layers are required to package a pHEMT amplifier chip, waveguide transitions and bends.
- DC bias circuit is also included in the Si block.

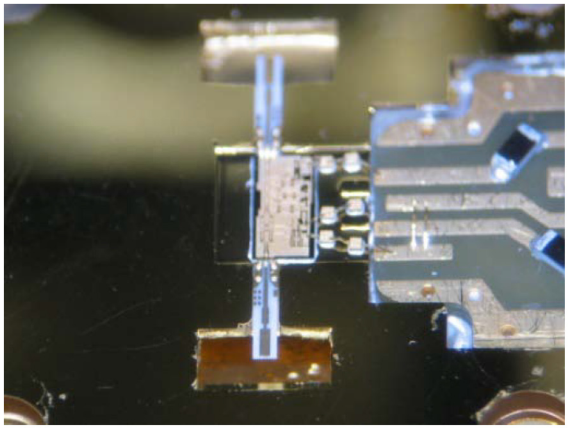


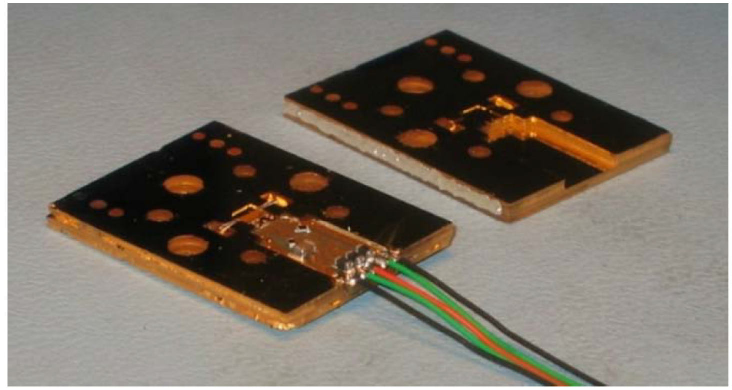


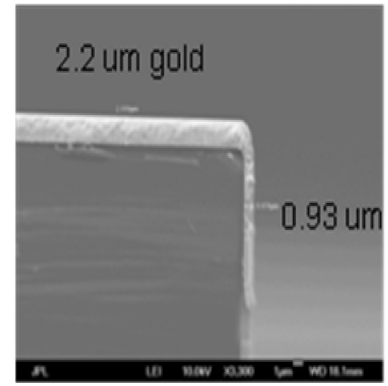
Super compact PA module

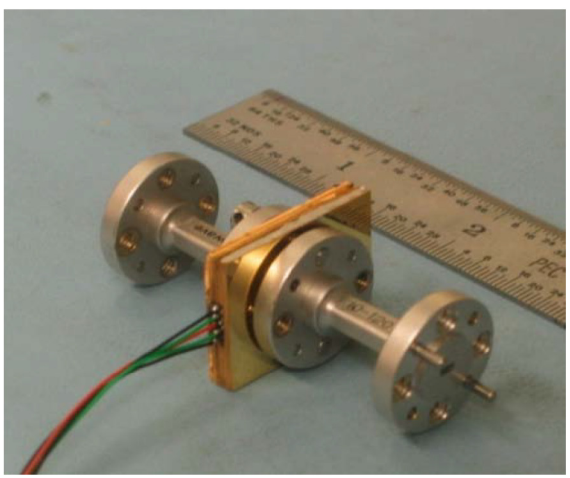
pHEMT MMIC

Deep RIE technology used to fab Si

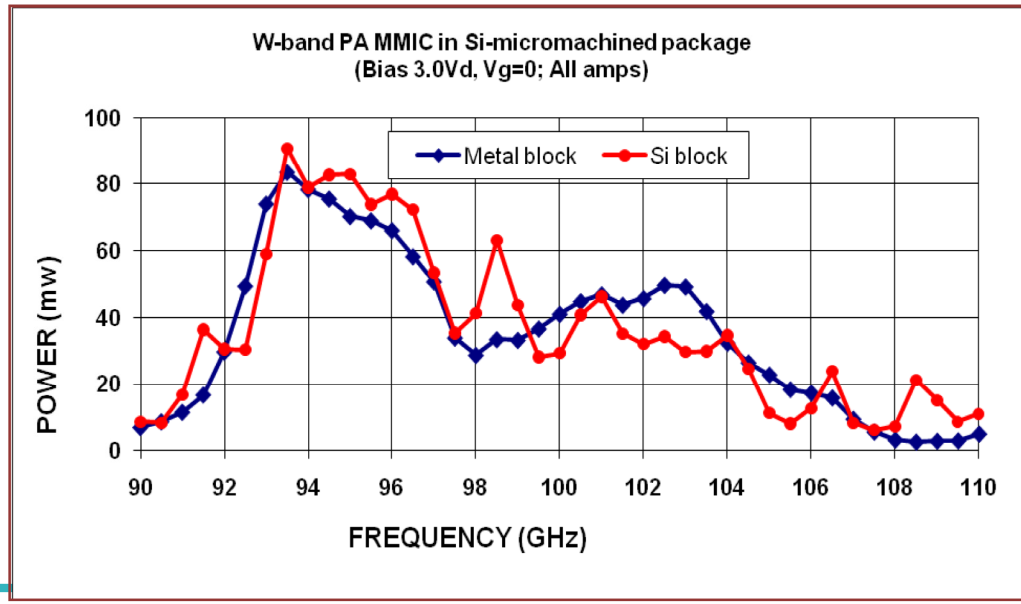






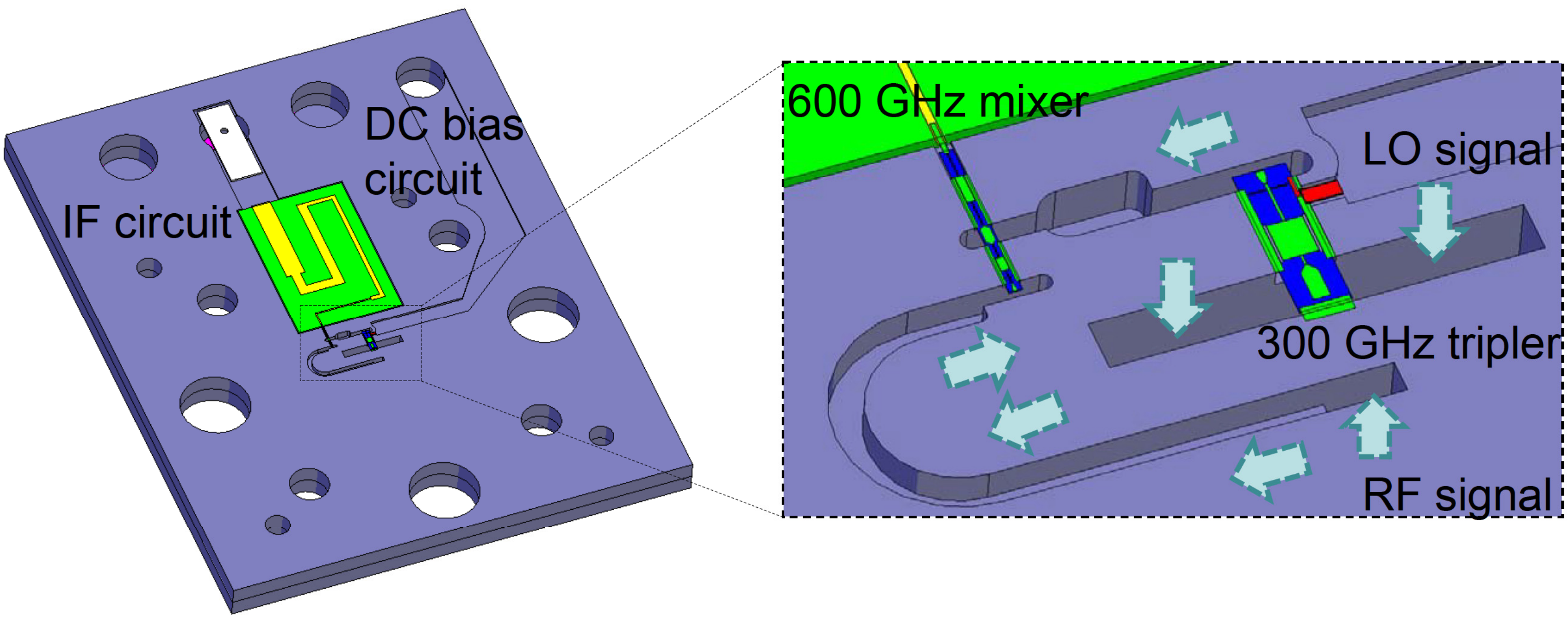


Completed module is only 7 g



Super compact 560 GHz RFE

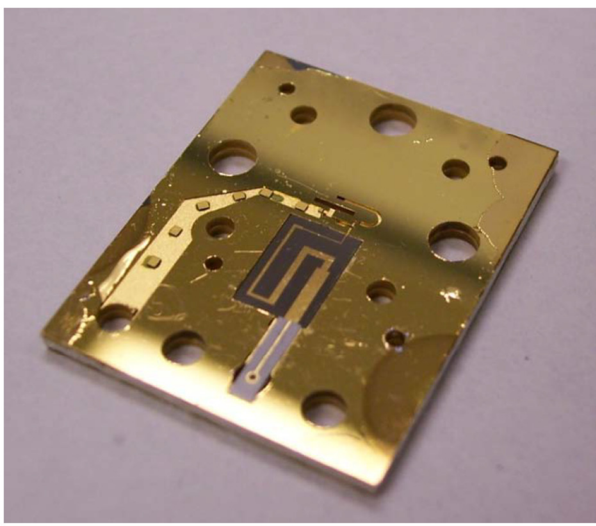
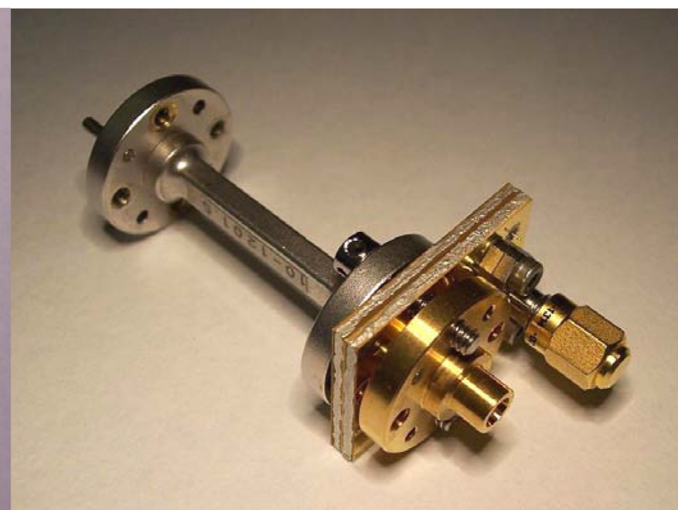
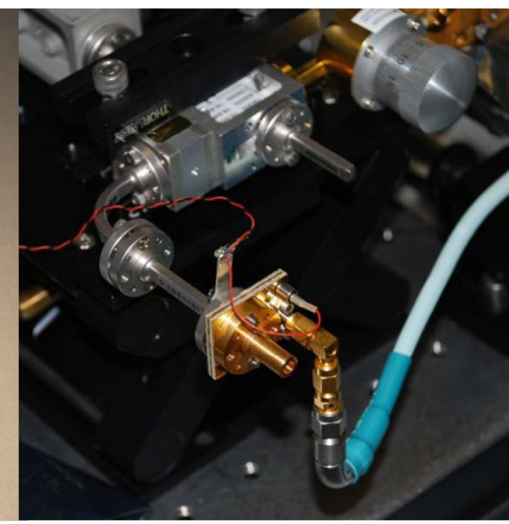
- Integrate in a Si package (4 layers) a 300 GHz MMIC tripler and 600 GHz MMIC sub-harmonic mixer



(Design courtesy of Bertrand Thomas)

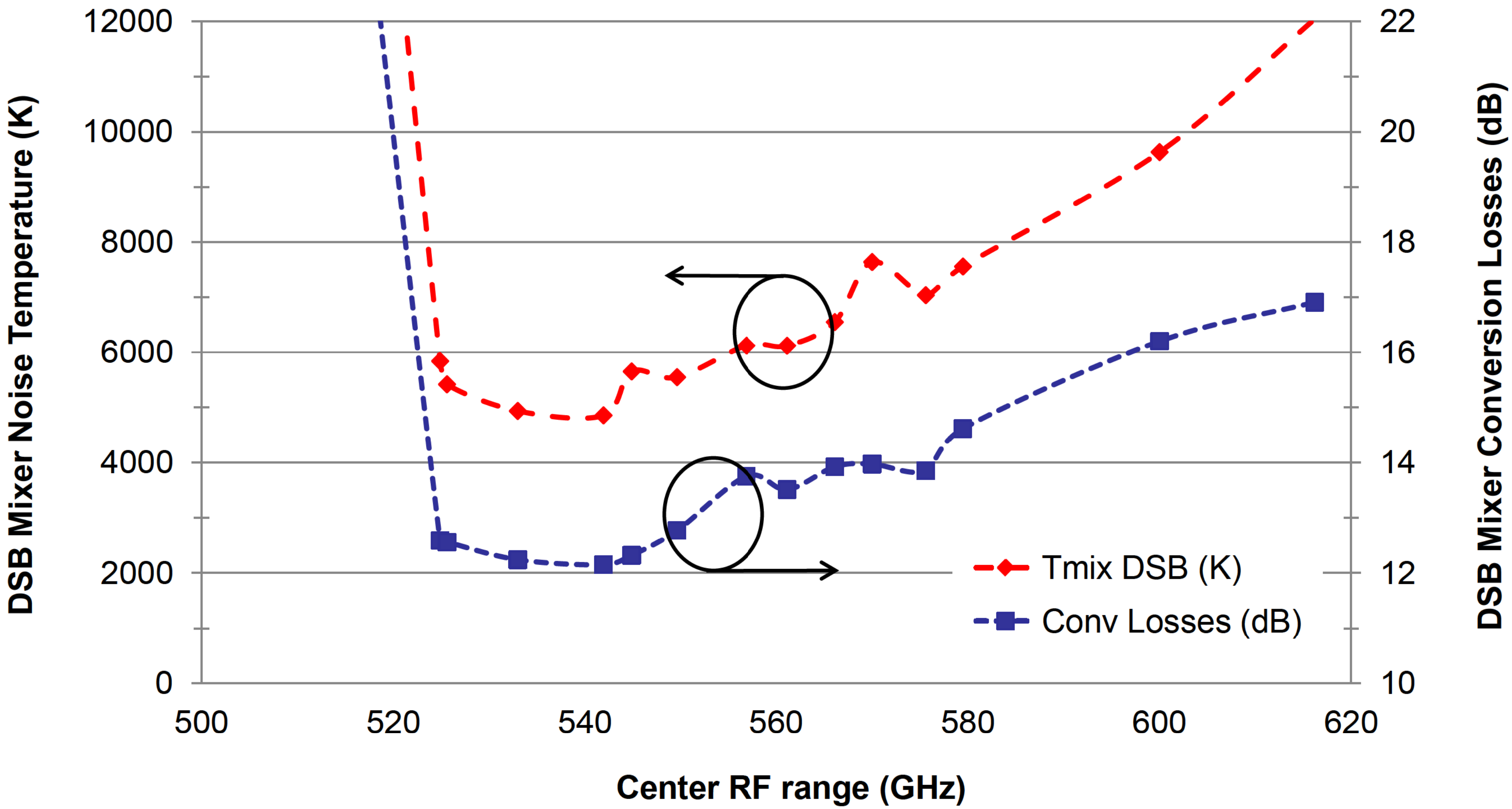
560 GHz RFE

- 20 x 25 x 3mm Si package
- WR-10 waveguide (input) & 560 GHz corrugated horn (output)
- SSMA and K-glass bead IF and DC connections

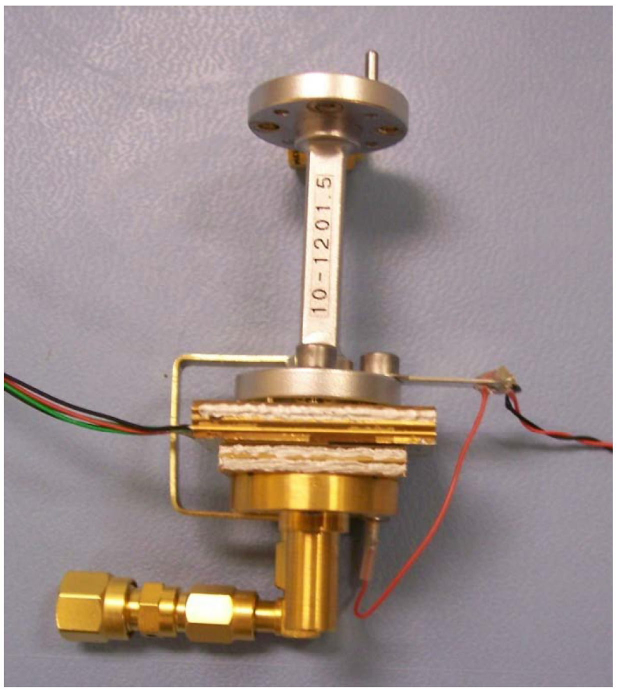
Measured Results

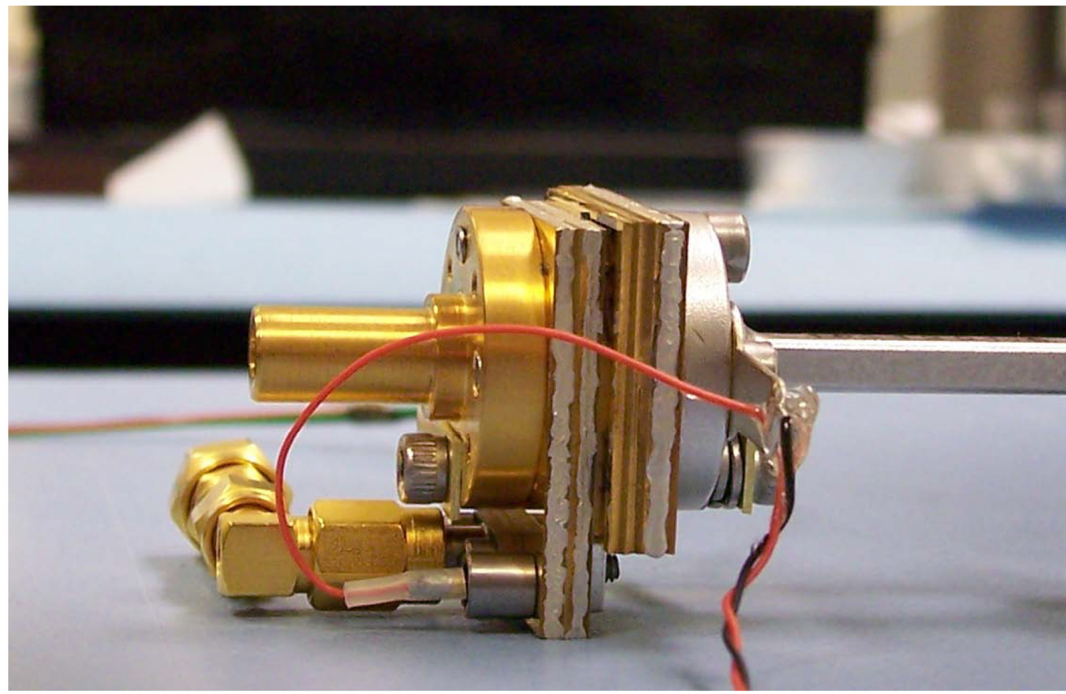
- IF frequency: 4 GHz. Not corrected for IF mismatch.
- Fundamental input power at W-band : 30-50 mW



Complete ROC front-end

- Si part is 8 mm thick.
- Size still dominated by UG387 flange.





Radiometer-on-a-chip

- Si part is 8 mm thick.
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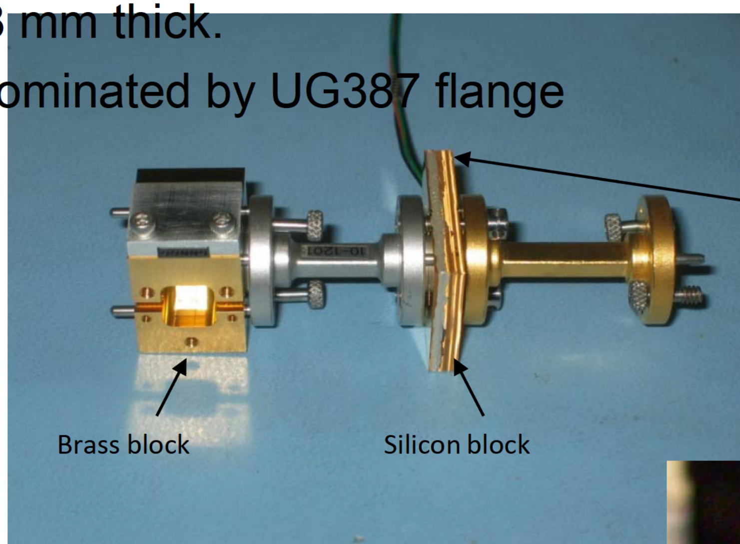
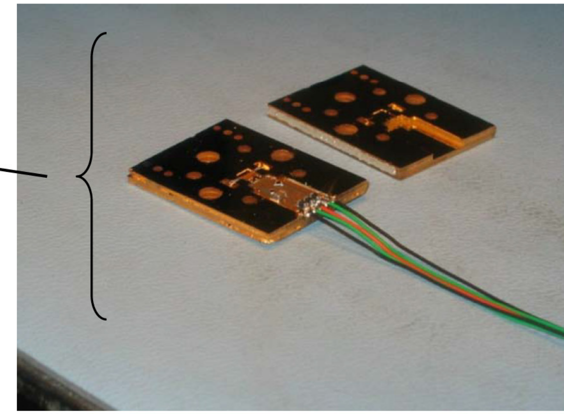
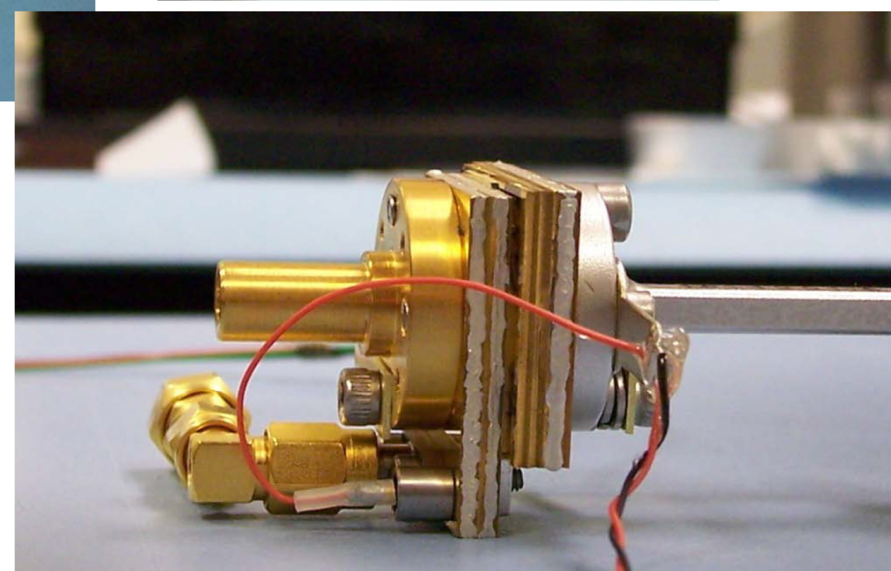
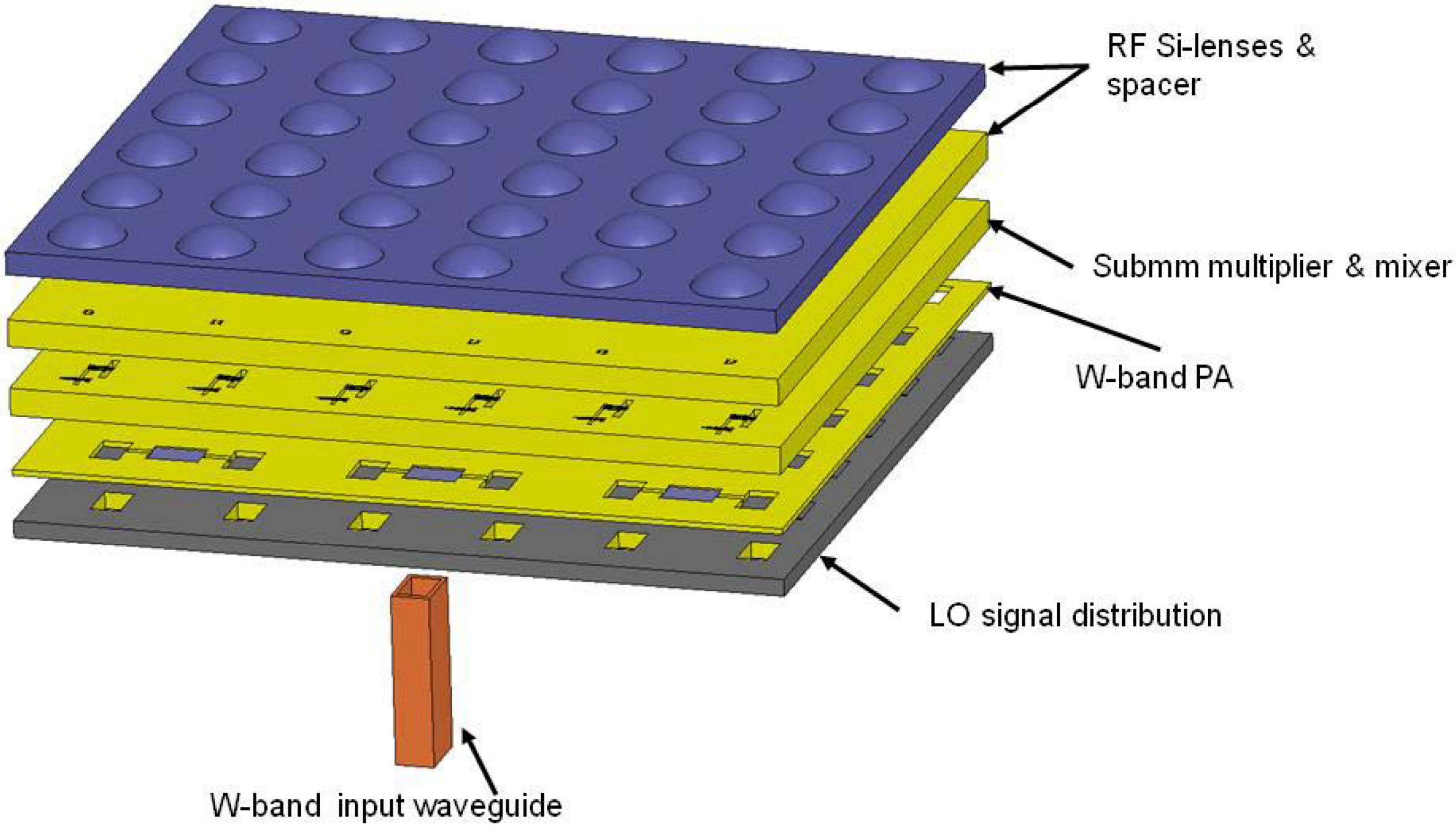




* DRIE technology and wafer-bonding technology are combined to assemble silicon based waveguide blocks
• Demonstrated with w-band power amp
• Demonstrated with 600 GHz RFE
• Provides technology to achieve massive power combining



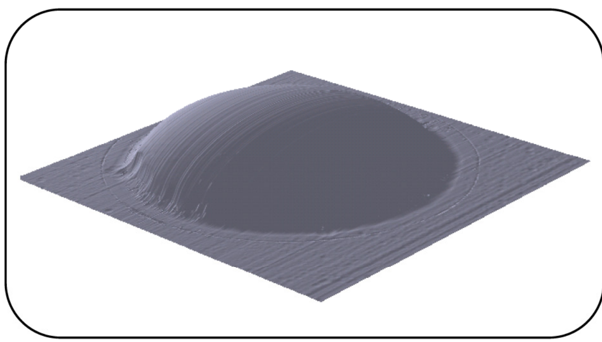
Towards a 2D array…

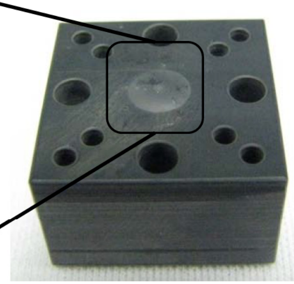


Development of Compact Integrated Receivers: Coupling feeds

-> Silicon lens used as antenna

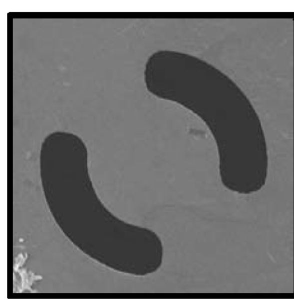
<u>Proof of concept</u> : Single pixel @ 560GHz

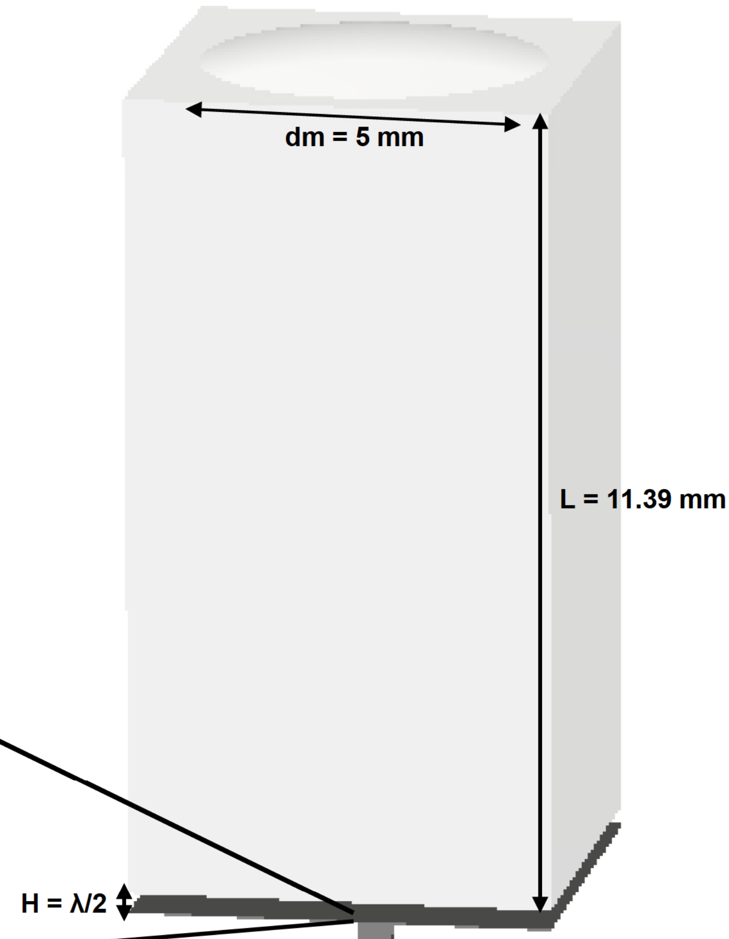




Silicon lens fabricated with a laser machine outside of the lab

-> Work in progress for silicon lens micromachined with UV photolithography and DRIE techniques

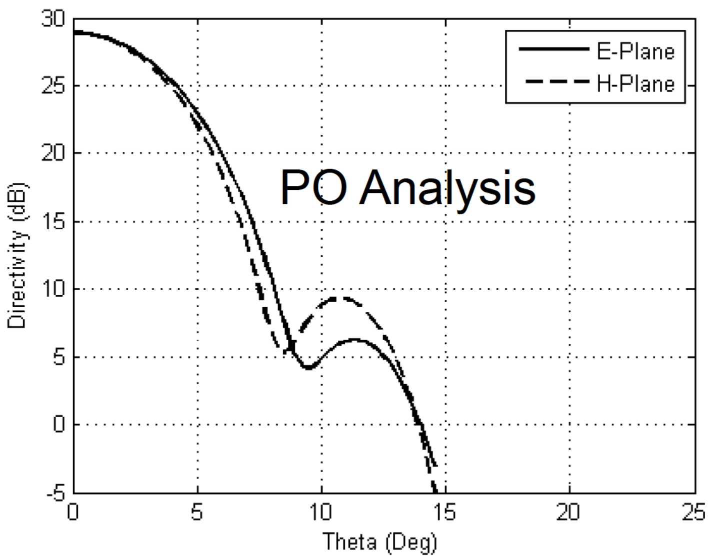




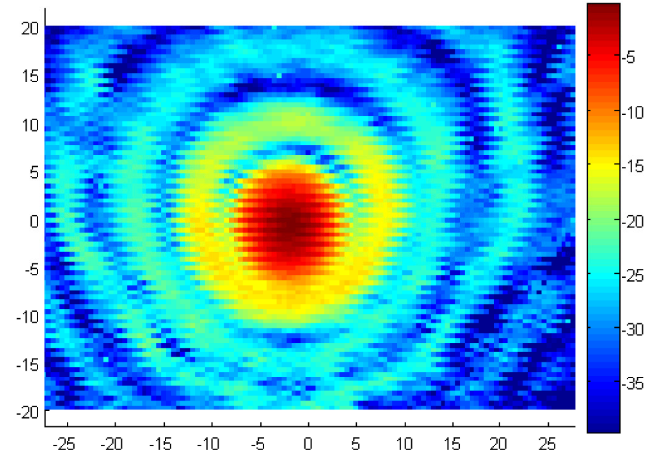
In collaboration with Dr. Nuria Llombart and Maria Alonso from Universidad Complutense de Madrid; Spain

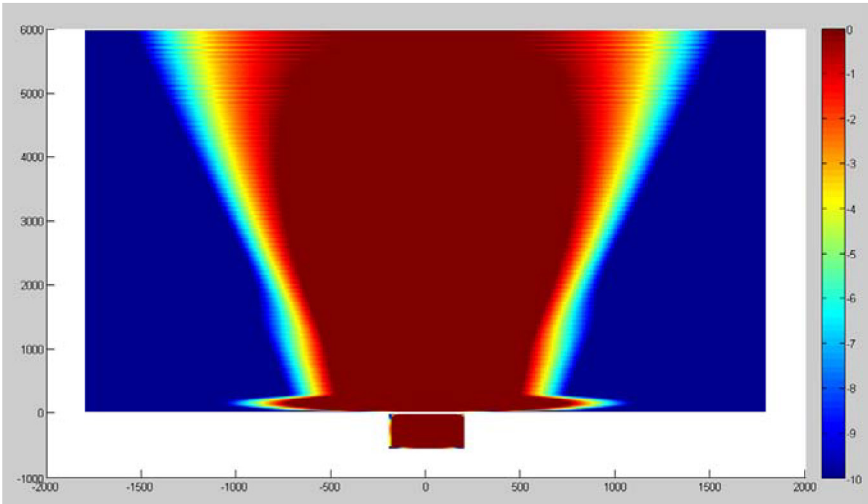
Development of Silicon Based Integrated Receivers

Proof of concept : Single pixel @ 560GHz



D = 28.5 dB
Aperture Efficency = 87 %





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Conclusion

- THz imaging arrays continue to be challenging to implement
- Significant reduction of size and mass of current receiver front-end has been achieved with the new Si-based ROC technology
- Preliminary results are encouraging
- Development of an array is under-way